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Publication date:
1996

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Sørensen, B. (1996). *Externality estimation of greenhouse warming impact*. Roskilde Universitet. Tekster fra IMFUFA No. 319 http://milne.ruc.dk/ImfufaTekster/

TEKST NR 319 1996

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1. August 1996

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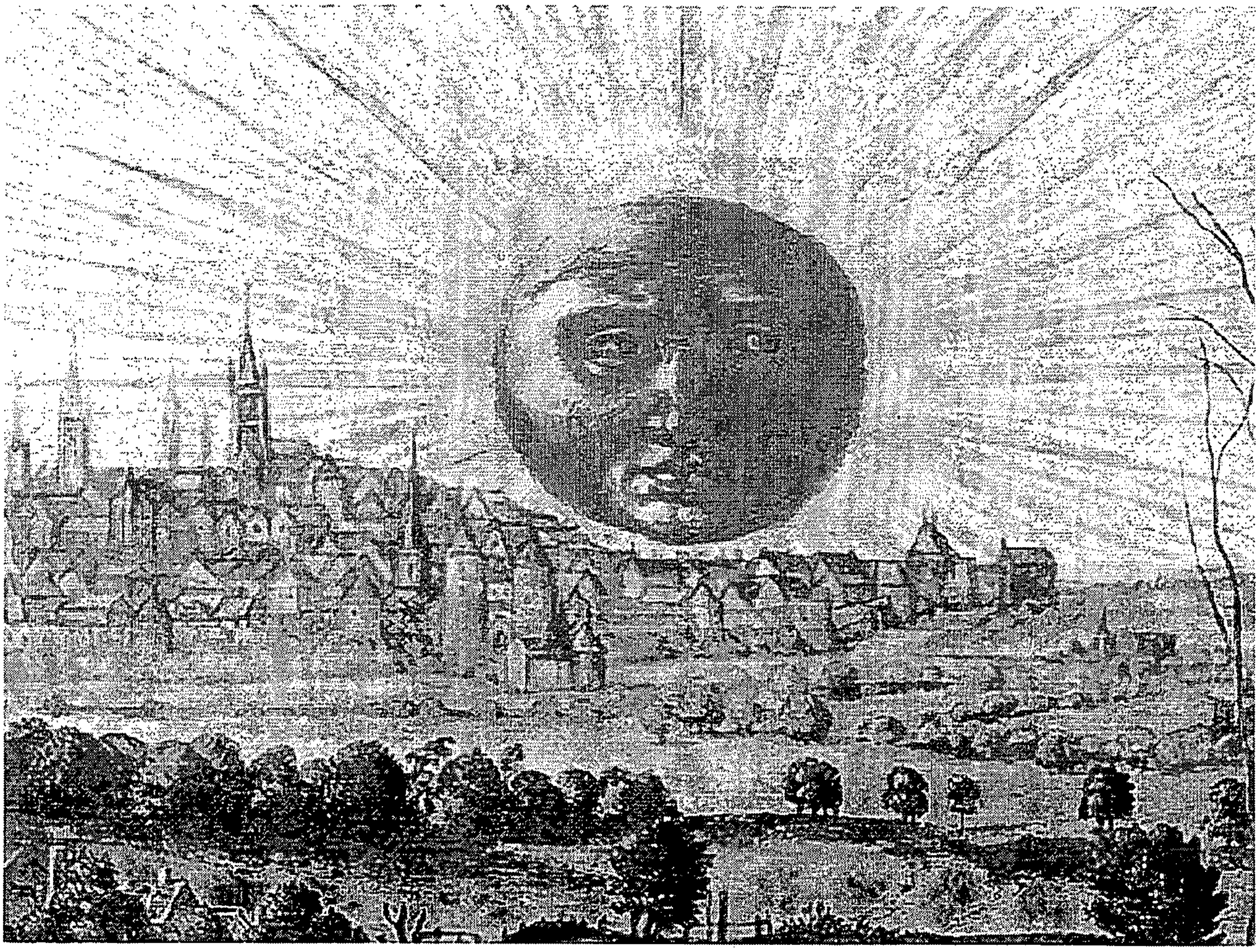

To be presented at Third International Conference on Carbon Dioxide Removal, Boston, USA
To be published in Energy Conversion and Management

TEKSTER fra

IMFUFA
ROSKILDE UNIVERSITETSCENTER
INSTITUT FOR STUDIET AF MATEMATIK OG FYSIK SAMT DERES FUNKTIONER I UNDERVISNING, FORSKNING OG ANVENDELSER

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IN EDUCATION, RESEARCH AND APPLICATION.

1. August 1996

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IMFUFA text no. 319, 8 pages. ISSN 0106 6242

Abstract - The impacts of greenhouse warming have been described by Working Group 2 of the most recent IPCC assessment. They include the impacts of changing vegetation zones on agriculture and silviculture, changes in the occurrence of crop pests and disease-carrying insects, as well as estimates of the effects of increased frequencies of extreme events such as heat waves, dry spells and floods. The present study attempts to quantify and valuate each of these impacts, integrated over the 21st century, under the assumption of continued injection of greenhouse gases into the atmosphere, leading to a doubling of atmospheric content around the middle of the 21st century.The results indicate, that over 90% of the adverse effects will occur in the Third World. This is because advanced agriculture as practised in the industrialized world is considered capable of adjusting crop species and practices according to the fairly slow changes in climate, whereas less developing countries will have difficulties in adjusting. Using monetizing assumptions typical of other studies (such as a statistical value of human life amounting to 3 million US $), one obtains externality costs roughly consistent with the earlier estimates by Cline, Frankhauser or Nordhaus, if restricted to the industrialized countries. This does not mean that the contributions are identical to those estimated earlier in all details. For the rest of the world, large discrepancies exist for reasons identified. These are primarily associated with starvation, increased incidence of malaria, schistosomiasis and cholera, as well as death associated with migration of people induced by floods or draughts. Furthermore, the impacts leading to human death can of course be reduced by assuming a lower statistical value of life in the less developed countries.The results are used to estimate per kWh externalities for specific types of energy use, such as power production using coal as a fuel, or automobile transport using gasoline as fuel. The purpose of producing these numbers is of course to provide evidence for the debate of how much one should spent on developing alternatives, such as de-carbonization of fossil fuels or renewable energy solutions.

Cover illustration from "Splendor Solis" (15th century book)

EXTERNALITY ESTIMATION OF GREENHOUSE WARMING IMPACTS

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ABSTRACT

The impacts of greenhouse warming have been described by Working Group 2 of the 1995 IPCC assessment. They include the impacts of changing vegetation zones on agriculture and silviculture, changes in the occurrence of crop pests and disease-carrying insects, as well as estimates of the effects of increased frequencies of extreme events such as heat waves, dry spells and floods. The present study attempts to quantify and valuate each of these impacts, integrated over the 21st century, under the assumption of continued injection of greenhouse gases into the atmosphere, leading to a doubling of atmospheric content around the middle of the 21st century. The result is a greenhouse warming externality constituting a sizable fraction of the global gross national product, provided that impacts are valued in the way normally done in externality studies for the industrialized world. As the greenhouse gas emissions are chiefly from industrialized countries, while the largest impacts are in those regions of the world least likely to reach stages of high development during the 21st century, this results poses a difficult geo-political problem. The implications for estimating externalities of particular energy conversion activities are briefly discussed.

KEYWORDS

Greenhouse warming impacts, monetarization, externalities of fossil energy use.

MONETIZING GLOBAL WARMING IMPACTS

Table 1 gives a list of impacts identified by the IPCC (1996), in terms of the additional number of people exposed to a range of risks, due to the average warming, sea level rise and additional extreme events predicted by the climate studies reviewed by the IPCC. As many impacts involve human deaths, the most important monetizing assumption is the choice of a statistical value of life (SVL), that allows human death to be presented as an expense to society, without embarking into any ethical discussion of the value of life. In a recent externality study for industrialized countries (European Commission, 1996), this value is taken as 3.3 million US $ (2.6 million ECU), which coincides with the compensation given in some European countries to government employees dying on the job. In this study, a similar value of 3 M$ will be used, but seasoned with a discussion of the implications of selecting a much smaller value for developing countries.

The individual entries in Table 1 are based on the sources indicated, with monetization of impacts evaluated as follows:

Table 1. Estimated global warming impacts during 21st century, for IPCC reference case (CO_2 doubling) (US$). H: high SVL of 3 M$ used throughout. L: SVL put at zero for Third World.

Impact description:	Ref.	Valuation H (T$)	Valuation L (T$)
Additional heatwave deaths (doubling, additional 0.1M/y, valued at 3 M$ each)	a	30	20
Fires due to additional dryspells (doubling)	b	1	0.5
Loss of hardwood- and fuelwood-yields (20% relative to 1980 production)	cde	4	1
Increase in skin-cancer due to UV radiation	b	3	3
Additional asthma and allergy cases (increase in pollen and air pollution due to warming)	b	3	1.5
Financial impact of increase in extreme events (doubling)	b	3	0.8
Increase in insect attacks on livestock and humans	b	?	?
Food production (failure to adopt new crops, increased pests and insect attacks, production loss 10-30%), (population at risk increasing from present 640M to 700-1000M), additional deaths from starvation due to crop loss (100M additional deaths, chiefly in developing countries)	f g	300	0
Deaths connected with migration caused by additional droughts or floods (50M deaths, the affected population being over 300M)	b	150	0
Increased mortality and morbidity due to malaria (presently 2400M at risk and 400M affected, increase due to warming 100M cases, in tropical and partly in subtropical regions, a 7- fold increase potentially possible in temperate regions assumed to be curbed)	b h	300	75
Increased mortality and morbidity due to onchocerciasis (presently 120M at risk and 17.5M affected, increase and spread due to warming 10M additional cases, primarily in developing countries)	b b,i	30	5
Increased mortality and morbidity due to schistosomiasis (presently 600M at risk and 200M cases, increase due to warming 25%, in dev. countries)	b	150	20
Increased mortality and morbidity due to dengue (presently 1800M at risk and 20M cases, increase due to warming 25%, in developing countries)	b b	15	0
Other effects of sanitation and freshwater problems connected with salt water intrusion, droughts, floods and migration (developing countries)	b	50	0
Loss of tourism, socioeconomic problems, loss of species, ecosystem damage, etc.	b	?	?
Total of valuated impacts (order of magnitude)		1000	100

Based on discussions in IPCC Working Group II, IPCC (1996) and on other sources as follows:
a. Kalkstein and Smoyer (1993)
b. McMichael et al., IPCC (1996), chapter 18.
c. Zuidema et al. (1994)
d. Kirschbaum et al., IPCC (1996), chapter 1.
e. Solomon et al., IPCC (1996), chapter 15.
f. Reilly et al., IPCC (1996), chapter 13 and Summary for Policymakers
g. Rosenzweig et al. (1993); Parry and Rosenzweig (1993)
h. Martens et al. (1994)
i. Walsh et al. (1981); Mills (1995)
The valuations involve further estimates and should be regarded as very uncertain.

The two valuation columns differ by the first using the high SVL globally, the second taking the SVL to be zero for developing countries, in order to display the geographical differences of impacts.

Heatwave deaths occur in major cities due to the heat island effect, possibly combined with urban pollution. The doubling estimated by Kalkstein and Smoyer (1993) is mostly due to increased occurrence at mid-latitudes (city temperature rise 2.5° assumed), and thus two-thirds are assumed to happen in industrialized countries. A case study in New York City (Kalkstein, 1993) finds an increased mortality of 4×10^{-5} over a 5-10 day period. The present annual New York rate of heat wave deaths is 320, and Kalkstein has collected similar numbers for a number of large cities around the world, experiencing days with temperatures above 33°C. The estimated doubling of incidence will thus imply an additional order of magnitude of 10^5 heatwave deaths, annually and globally, valued at 30 T$ over the 100 year period. Uncertainties come from possible acclimatization effects, and from increased populations in large cities expected over the 21st century.

The doubling of fires causes mainly economic loss, assumed to be evenly distributed between developed and developing countries, whereas the 20% losses of hardwood and fuelwood yields is predicted to follow a complex geographical pattern (Kirschbaum et al, IPCC, 1996, chapter 1), but with the highest losses occurring in tropical regions (Solomon et al., IPCC, 1996, chapter 15). It is here assumed that 75% of the economic losses pertains to developing countries. The increased number of skin cancer cases due to an assumed 10% loss of ozone is mainly occurring at higher latitudes (IPCC, 1996, chapter 18).

Additional allergy cases would be associated with increased levels of pollen and air pollution due to heating and would occur predominantly at lower latitudes, whereas asthma incidence is highest in humid climates, expected to be enhanced at higher latitudes (IPCC, 1996, chapter 18). The impacts are assumed to be equally divided between developed and developing regions. Due to expected shortfall of hardwood supply relative to demand during the 21st century, the actual economic value may be considerably higher than the estimate given in Table 1. The financial loss associated with a predicted doubling of extreme events (draughts and floods, IPCC, 1996, chapter 18) is assumed to occur 75% in developing countries. The predicted incidence of insect bites is not valued, but could have an economic impacts, e.g. on livestock production.

One major issue is the impact of climate change on agricultural production. Earlier evaluations (e.g. Hohmeyer, 1988) found food shortage to be the greenhouse impact of highest importance. However, the 1995 IPCC assessment suggests that in developed countries, farmers will be able to adapt crop choices to the slowly changing climate, such that the impacts will be entirely from Third World farmers lacking the skills to adapt. The estimated production loss amounts to 10-30% of current global production (Reilly et al., IPCC, 1996, chapter 13), increasing the number of people exposed to risk of hunger from the present 640 million to somewhere between 700 and 1000 million (Parry and Rosenzweig, 1993). There are also unexploited possibilities for increasing crop yields in the developing countries, so the outcome will depend on many factors, including speed of technology transfer and development. Assuming a lower estimate of 100 million additional starvation deaths during the 21st century, one arrives at the 300 T$ figure given in Table 1, all occurring in the Third World. This is also the case for deaths associated with migration induced by extreme events, estimated at 50 million.

The other major impact area is death from diseases transmitted by insect vectors influenced by climatic factors, such as mosquitoes. For Malaria, there are presently 2400 million people at risk (McMichael et al., IPCC, 1996, chapter 18), and an additional 400 million expected due to greenhouse warming and its implied expansion of the geographical area suited as habitat for the malaria-carrying mosquitoes (Martens et al, 1994). This will involve subtropical and even some temperate regions, but also in tropical regions, the incidence of malaria is predicted to increase. Assuming 100 million additional deaths from malaria during the 21st century, of which 75% in the tropics, one arrives at the figures given in Table 1. Large uncertainties are associated with the possibilities of mitigating actions in the subtropical and temperate regions. Also for onchocerciasis, vector populations are expected to both increase by 25% at current sites (Mills, 1995) and to spread to new sites (Walsh et al., 1981), leading to 10 million additional cases. Schistosomiasis may also spread in the subtropical regions, whereas dengue and yellow fever is expected to remain in the tropics. Table 1 reflects these expectations, through its distribution of impacts between developed and developing regions, and it also gives an estimate of deaths occurring due to sanitation problems connected with salt water intrusion into drinking water (due to sea-level rise) and larger migrating populations, mainly in the developing countries (assuming that immigration into industrialized countries continues to be controlled). The economic consequences of other identified impacts, such as loss of species, effect on tourism, etc., have not been estimated.

The overall impacts are of the order of magnitude 10^{15} US \$, when using the SVL of industrialized countries, and one order of magnitude lower, if Third World impacts are valued at or near zero. This spells out the greenhouse impact dilemma, that 90% of the damage is in the Third World, much higher than their share in causing the problem. The IPCC Working Group 2 identification of a number of impacts specifically occurring in the low-latitude regions explains why the impact estimates are so much higher than those of early work based upon and extrapolated from industrialized regions (Cline, 1992; Frankhauser, 1990; Nordhaus, 1990). Other factors contributing to this result include the high SVL, and the assumptions of less ability to mitigate impacts in the Third World (by switching food crops, building dikes to avoid floods, and so on). If the impacts of the present study, evaluated with the uniform high SVL, are distributed equally over the 100-year period, the annual cost of greenhouse warming is found to be roughly 40% of the current global GNP.

APPLICATIONS OF GREENHOUSE WARMING EXTERNALITIES

The translation of the 10^{15} US\$ impact from greenhouse emissions into externalities for specific energy activities may be done in the following way: It is assumed that about 75% of the forcing comes from energy-related emissions, and of these 17.5% are from natural gas, 40% from coal and 42.5% from oil. Modern power stations typically emit 0.27 kgC/kWh if coal-fired, 0.16 kgC/kWh if gas-fired and 0.21 kgC/kWh if oil-fired. The transportation sector mainly uses oil products and is responsible for 19.4% of the energy-related carbon emissions or 1.12 TkgC/y, which for gasoline driven automobiles corresponds to 659 gC/liter or about 49 gC per vehicle-km at an average of 13.5 km per litre of gasoline. The doubling of atmospheric greenhouse gases is now assumed to be due to 50 year's of emission at an average level 50% above the present one (corresponding to a doubling of fuel usage during the period). Using these assumptions to distribute the share of the total greenhouse externality on each activity, one obtains 0.40 US\$/kWh for coal-fired power stations and 0.072 US\$/vehicle-km for gasoline-driven cars.

The non-climate externalities associated with air pollution and mining accidents are about 0.06 US\$/kWh for the fuel chain associated with a European state-of-the-art coal power plant (European Commission, 1996; Sørensen, 1996; these impacts would be larger for the current average power plant). In this case, the greenhouse warming impacts of 0.4 \$/kWh are thus dominating.

Another example is that of externalities associated with ownership and use of motor vehicles, shown in Table 2. In this case, there are many externalities besides greenhouse warming, due to the impacts of traffic. Common assumptions for all the calculations are the use of an average-size car, driving 200000 km in 10 years with an average efficiency of 13.5 km per liter of gasoline (corresponding to mixed urban and highway driving). The greenhouse warming externality of 7.2 USc/km is evaluated above. The health effect caused by air pollution from car exhaust is taken as 4.1 USc/km, a number arrived at in several of the Scandinavian studies quoted. Also the accident statistics gives a firm basis for estimation (although the rate of accidents varies considerably between countries - the value used here corresponds to Denmark), but the value of police and rescue team efforts, hospital treatment, lost workdays and lives all have to be chosen. The SVL is again assumed to be 3 M\$, and for time loss a figure of 9.4 \$/h is used (based on an interview study on perceived values of waiting time; Danish Technology Council, 1993). This is a "recreational" value in the sense that it rather corresponds to unemployment compensation than to average salary. The "stress and inconvenience" line takes into account the barrier effect of roads with traffic, causing e.g. pedestrians to have to wait (e.g. at red lights) or to walk a larger distance to circumvent the road barrier. This may again be valued as time lost.

The noise impact is estimated at 3.2 USc/km based on hedonic pricing (i.e. the reduction in the value of property exposed to noise (e.g. houses along major highways as compared to those in secluded suburban locations) (Danish Transport Council, 1993). A similar approach is taken to estimate the visual degradation of the environment due to roads, signs, filling stations, parking lots and so on. Property values have been collected in 1996, for detached houses of similar standard, located at the same distances from the Copenhagen city centre (but outside the high rise area, at distances of 10 to 25 km from the centre), but exposed to different levels of visual and noise impact from traffic. The externality is then taken as the number of people exposed times the sum of property losses. The property loss found is 25-45%, and the total damage for 0.5 million people with 0.2 million houses and cars is 20.5 G$ or 54 USc/km, of which half is assumed to derive from visual impacts. A further reduction by a factor two is introduced by going from a suburban environment near Copenhagen to a country average. The value arrived at (for Denmark) is the 13.8 USc/km given in Table 2. The direct economic impacts include capital expenses and operation for cars and roads, as well as property value of parking space in garages, carports or open parking space, but omitting any taxes and duties, and the benefits from driving are taken at the value of public transport (considering that differences in convenience and inconveniences such as not being able to read when driving even out). Time use is as mentioned above derived from a contingency valuation (i.e. interviews). The "fairly calculated" cost of driving a passenger car, i.e. all direct costs and externality items except benefits and time use, add up to 0.65 US$/km, of which 0.07 are related to owning the car (purchase price without taxes plus environmental impacts of car manufacture), and the remaining 0.58 US$/km are related to driving the car. A fair tax level, reflecting external costs, would then be divided into a vehicle tax of around 4100 US$, and a kilometers-driven component, that levied onto the fuel would amount to about 5 US$ per litre.

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Table 2. Impact from average passenger car (1990).

Enviromental impacts	type of impact: emissions (g per kWh of fuel)	monetised value (mUS$ per vehicle-km)	monetised value (mUS$ per kWh of fuel)	uncer-tainty & ranges
Environmental emissions:				
Car manufacture, decommissioning	average industry	18	28	H
Car maintenance	NQ			
Road construction and maintenance	NQ			
Operation:				
CO_2	277			L
NO_x (may form aerosols)	2.9			M
CO	17			M
HC	3.0			M
particles	0.06			M
Health effects from air pollutants		41	63	H,l,n
Greenhouse warming (cf. Table 1)	mainly from CO_2	72	109	H,g,m
Noise	av. increase 1.5 dB, variations are large	32	49	H,l,n
Environmental & visual degradation (from roads, signs, filling stations,etc.)		138	208	H,l,m
Health and injury				
Occupational (car/road construction and maintenance)	NQ			
Traffic accidents (incl. material damage, hospital and rescue costs):		107	161	M,l,n
Based on deaths (SVL=3 MUS$)	2.4×10^{-8} per kWh-fuel			
heavy injury	24×10^{-8} per kWh-fuel			
light injury (when reported)	16×10^{-8} per kWh-fuel			
Stress and inconvenience (e.g. to pedestrian passage)		33	50	H,l,n
Economic impacts				
Direct economy (cars, roads, gasoline, service and maintenance)	taxes excluded	276	420	L,l,n
Resource use	significant		NQ	
Labour requirements and import fraction (Denmark)	about 50% of direct costs are local		NQ	
Benefits (valued at cost of public transportation)		357	543	M,l,n
Time use (contingency valuation)		156	237	H,l,n
Other impacts	NA			

Sources: Danish Technology Council (1993); Danish Road Directorate (1981), Danish Statistical Office (1993), Danish Department of Public Works (1987), Christensen and Gudmundsen (1993), and own estimates. NA= not analysed, NQ= not quantified. Values are aggregated and rounded (to zero if below 0.1 mecu/kWh). (L,M,H): low, medium and high uncertainty. (l,r,g): local, regional and global impact. (n,m,d): near, medium and distant time frame.